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AROMA: An Adapt-or-Reroute Strategy for Multimedia Applications over SDN-based Wireless Environments

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Abstract—To support new and advanced multimedia-rich applications and services while providing satisfactory user experience, the underlying network infrastructure needs to evolve and adapt. One of the key enabling technologies of the next generation (5G) networks is the integration of Software Defined Networking (SDN) within a heterogeneous wireless environment to enable interoperability and QoS provisioning. Leveraging on the features of the SDN paradigm, it is possible to introduce new solutions to handle the increasing mobile video transmission challenges with strict QoS requirements, such as: low delay, jitter, packet loss, and high bandwidth demands. However, degradation and instability perceived from video traffic makes it difficult to satisfy various end-users. In this context, this paper proposes AROMA, an Adapt-or-reRoute strategy for Multimedia Applications over SDN-based wireless environments. AROMA enables QoS provisioning over multimedia-oriented SDN-based WLAN environments. The proposed solution is evaluated using a real experimental test-bed setup.

I. INTRODUCTION

Over the recent years, there has been a notable shift in today's telecommunication networks due to the rapid increase in the popularity and usage of multimedia-based applications. The proliferation of high-end mobile devices, tablets and other end-user equipment represents a major source of generating traffic since the end-users rely on high speed networks especially for the new multimedia-rich applications [1] with strict Quality of Service (QoS) requirements. Cisco predicts [2] that the global video traffic will account for 82% of the global IP traffic by 2021 through video-based applications, such as: video conferencing, video streamed-gaming, Internet video, etc. Moreover, the popularity of live Internet video is set to be the fastest growing segment which will account 15-fold, from 3% in 2016 to 13% by 2021 in courtesy of social media streaming applications offered by Facebook, Instagram, Face Time, etc. Another segment of bandwidth-hungry video-based applications like virtual and augmented reality are estimated to grow 20-fold between 2016 and 2021 at 82% compound annual growth rate (CAGR).

This tremendous growth in mobile broadband traffic puts significant pressure on the underlying network technology,

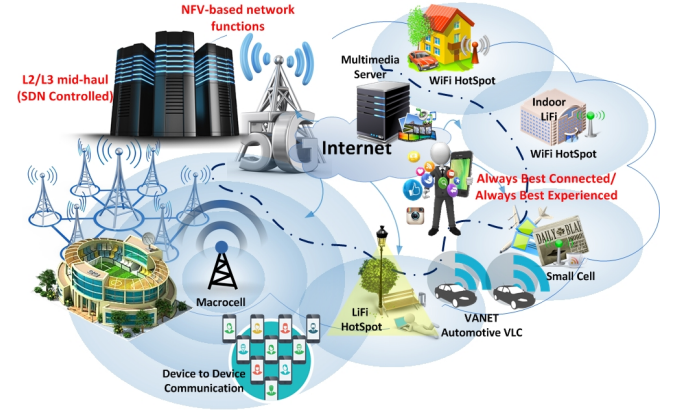


Fig. 1. SDN-based Heterogeneous 5G Environment

especially with video being one of the most bandwidth-consuming of all applications [3]. To overcome these challenges the fifth generation (5G) of wireless communications is seen as a promising solution for heterogeneity and interoperability as illustrated in Fig. 1. An important and key enabling technology for 5G is the software defined network (SDN)-based heterogeneous network (HetNet) aiming at virtualizing the network components and the spectrum resources in order to enable *Anywhere, Anytime, Any One, Any Device* connectivity and consequently the provisioning of QoS and Quality of Experience (QoE) to the mobile users.

SDN is an emerging network paradigm with four fundamental network principles [4]. First, it breaks the vertical integration by separating the control plane from the underlying data plane. Second, it uses flow-based packet forwarding decisions instead of destination based. Third, the underlying network infrastructure is abstracted from the programmable application layer and lastly, an SDN controller is introduced to monitor the network resources utilization. The success of SDN within both the research community and networking industries allows network administrators to design how a flow should be handled using a centralized entity that enables adaptable management and control. However, optimizing video flows within a SDN-based environment remains a fundamental challenge since

QoS provisioning is required to maintain the increasing bandwidth demands for computational intensive services [5].

This paper proposes **AROMA**, an **Adapt-or-reRoute** strategy for **Multimedia Applications** over SDN-based wireless environments. AROMA is a new resource management solution to enable QoS provisioning over multimedia-oriented SDN-based wireless environments. A real experimental test-bed setup is implemented to evaluate the performance of the proposed solution when compared to the default SDN. The performance evaluation is done in terms of throughput, packet loss, PSNR and MOS.

II. RELATED WORKS

QoS provisioning for video traffic over wireless networks is considerable challenging due to the strict QoS requirements of video traffic such as: high bandwidth demand, reduced packet loss and delay [6] in contrast to the fluctuating behavior of a wireless network. In order to solve the problem of streaming video over wireless network while maintaining high end-user perceived quality levels, different video adaptation techniques have been proposed in the literature [7], [8]. The most popular adaptation techniques are the bitrate switching solutions which involve the server storing multiple versions of the same video, pre-encoded with different characteristics to have a set of different video qualities to choose from. Switching between different video quality levels is done based on different device-related parameters, such as energy consumption, device characteristics and user preferences [7] or network-related parameters, such as signal strength and packet loss [8].

Similarly, significant effort has been placed in this area to improve users' QoE. Chiroiu et al. [9] analyze the quality of video traffic over the Internet using traffic engineering techniques that will supply enough bandwidth for video streaming application. Dong et al. [10] fine-grained the Internet video traffic based on hierarchical clustering. The authors study the QoS features and network requirements for some typical video traffic classification. The proposed method effectively improves the statistical features for video traffic in comparison to existing methods. Performance analysis of WLANs under bursty and correlated video traffic was presented by Najjari in [11]. The authors highlight how burstiness and correlation of video traffic impacts the QoS performance metric under Batch Markovian Arrival process (BMAP). They argue that BMAP traffic greatly deteriorates performance of 802.11-based WLANs compared to the traffic modeled using Poisson and Markov Modulated Poisson Process. Dao et al. [12] investigated the handling of real time video traffic over software-defined radio access networks. The authors proposed four approaches to enable the user's QoE provisioning, such as: (1) introduction of online approach that dynamically estimates the number of video flows in the system; (2) applying traffic engineering techniques by means of optimizing the congested flows; (3)

a radio coordination method to enhance stable video rate; (4) applying coding scheme that will support mobile users.

The adoption of SDN offers wide advantages over the traditional networks through a simplified network management layer. Al-Jawad et al. [13] propose a policy-based management framework over SDN for QoS provisioning. The proposed solution will dynamically enforce new decisions on the underlying SDN switches to adapt the network state to the current demanded high-level policies. In [14], the authors propose LearnQoS, an intelligent QoS management framework for multimedia-based SDNs. LearnQoS makes use of reinforcement learning to optimize the operation of a policy-based network management (PBNM) which ensures the compliance of QoS requirements for video traffic over SDN. Kucminski et al. [15] investigate the use of a new routing algorithm for QoS provisioning over SDN-based networks. In [16] a Bayesian network model and Bayes' theorem were used in to find the most feasible path that satisfies the QoS constraint over SDN. MiceTrap was proposed in [17] which makes use of flow aggregation together with a software-configurable weighted routing algorithm to improve load balancing over SDN. A compression-based technique for SDN aiming at decreasing the link usage for QoS applications while maintaining increased network observability was proposed in [18]. However, these approaches did not consider the wireless integration into SDN. Araniti et al. [19] evaluated the potential advantages introduced by SDN over wireless networks.

In contrast to the related works, this paper proposes AROMA which is a combined approach of video adaptation and QoS-based routing. Additionally, a real experimental test-bed is built to analyze the performance of the proposed solution.

III. AROMA SYSTEM ARCHITECTURE

The proposed AROMA framework for resource management over SDN-based WLAN environments is illustrated in Fig. 2. AROMA makes use of SDN to monitor and control the network, and based on the current network conditions it will decide either to reroute the multimedia stream or to adapt the quality level of the multimedia stream. AROMA differentiates between congestion inside the core network or at the wireless access network. If congestion is detected inside the core network, then the multimedia traffic is rerouted on a better path. However, if packet loss is detected at the wireless access network, the multimedia stream will be adapted to a lower quality level. Thus, AROMA framework consists of an SDN controller which integrates custom modules to manage the traffic, SDN switches for wired and wireless that store the flow tables, a multimedia server that stores the videos and a wireless end-user. OpenFlow protocol is used for the interaction between the SDN controller and the SDN switches.

The multimedia server stores several copies of the same video content encoded at different quality levels by using different characteristics, such as different frame rates, frame

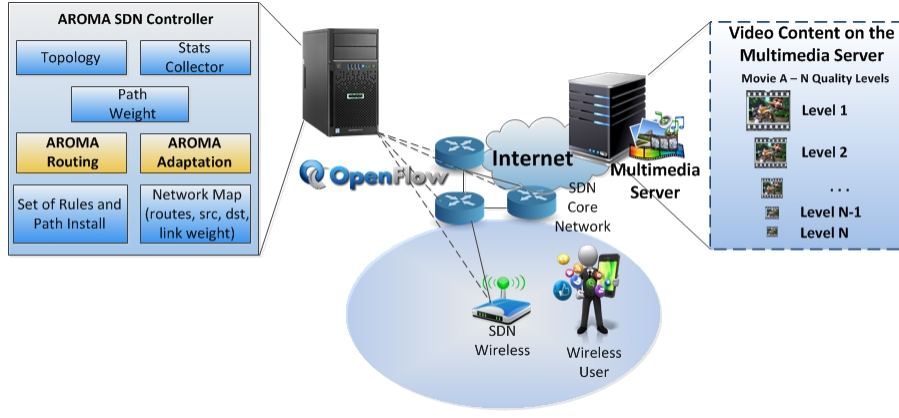


Fig. 2. AROMA System Architecture

sizes, bitrates, etc. For example, the multimedia server can store a number of N quality levels for a certain Movie A, with Level 1 being the highest quality level up to Level N the lowest quality level. The SDN controller will monitor the network conditions and will notify the multimedia server when the quality level needs to change.

To this extent, the AROMA SDN controller consists of the following functional modules:

- Topology module - stores the information related to all the active devices, ports and links within the SDN network. This information is collected by generating link events using Link Layer Discovery Protocol (LLDP) packets.
- Stats Collector module - is used to periodically collect traffic load information on the network links from the SDN switch ports counters.
- Path Weight module - is using the information from the stats collector module to compute a weight value for each path in the topology.
- AROMA routing module - computes a new route for the flows in the case congestion is detected.
- AROMA adaptation module - triggers the Multimedia server to adapt the quality level of the multimedia stream when packet loss is detected in the wireless network.
- Set of Rules and Path Install module - sends the rules and the paths as generated by the AROMA routing and AROMA adaptation modules.
- Network Map module - stores the overall network map.

A. AROMA Routing

The SDN controller has the global view of the overall network topology, hence it can monitor the load of the network links periodically in an effort to relieve congestion and improve performance of the network. The AROMA Routing module makes use of a weighted routing algorithm as proposed in [17]. The AROMA Routing module will handle the new incoming video flows as well as it will re-route the existing ones if necessary, when congestion is

detected. The SDN controller has a view of all the possible paths a flow can take between any source and destination. Thus, for each path the Path Weight module inside the SDN controller will compute a weight based on the current network load. The load information for each network link is collected by the SDN controller from the switch port counters. This information will help the SDN controller to identify any imbalance in the distribution of the traffic load over the network and compute the path weight. The path that has the highest weight will be selected as the target path.

Thus, for any path $i \in N_{(s,d)}$, where $N_{(s,d)}$ is the set of shortest paths between any source-destination pairs, the path weight w_i is computed using eq. (1) [17]:

$$w_i = 1 - \frac{(\sum_j \sum_k LUR_{kji})/M_i}{\sum_i (\sum_j \sum_k LUR_{kji})/M_i} \quad (1)$$

where LUR_{kji} is the *link utilisation ratio* defined as the ratio of the traffic link load and the link capacity on segment k of subpath j of path i , M_i represents the number of subpaths of path i . The path weight w_i , takes values within the interval $[0,1]$ and the highest the value is the less loaded the network path is. Thus, the network path with the highest path weight will be selected as the target path and the set of rules and path install instructions will be sent to the SDN switches which will route the flows accordingly.

Whenever the SDN controller detects congestion in the wired network it will trigger the AROMA routing module to re-route the affected video flows which have strict QoS requirements on the path with the highest path weight.

B. AROMA Adaptation

If loss is detected within the wireless network, then the AROMA Adaptation module is triggered. Within the wireless network, apart from collision-based losses, there can also be losses due to wireless errors or drop in signal strength. In this case, an adaptation technique as the one proposed in [8] can be employed to cater for the video flow QoS requirements and maintain a good user perceived quality.

TABLE I
SUMMARY OF EXPERIMENTAL HARDWARE

Hardware	Version	Purpose
Raspberry Pi 2	Model B	OVS
Raspberry Pi 3	Model B+	OVS+Hostapd
USB 3.0 fast Ethernet adapter	TP-Link UE300	Multiple Ethernet Ports on OVS
Switch	Net Gear ProSAFE GS108UK	Connect the Raspberry Pis to ONOS via eth0
Dell Laptop	Latitude E6530	ONOS Controller
Apple Laptop	MacBook Retina	Multimedia Server Host
Samsung Tablet	GT-N800	Video Traffic
Asus Laptop	VivoBook F510	Background Traffic
Apple Laptop	MacBook pro13	Background Traffic

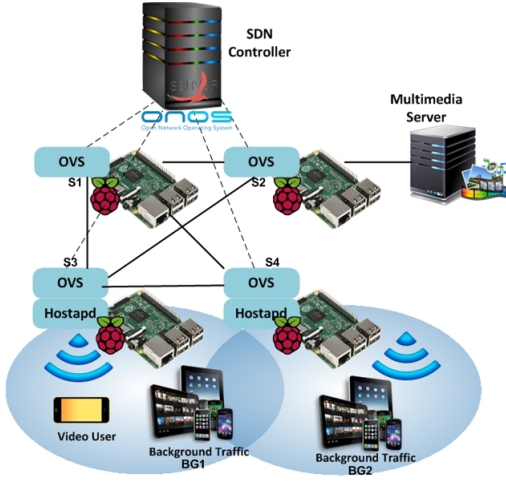


Fig. 3. Experimental Test-Bed Setup

If the loss detected in the wireless environment goes above a pre-defined threshold, the AROMA Adaptation module will send a notification to the multimedia server to switch to a lower quality video stream. If there is no loss detected within a certain interval, the AROMA Adaptation module will notify the multimedia server to switch the video transmission to a higher quality level.

IV. EXPERIMENTAL SETUP

A. Experimental Test-Bed Setup

We evaluate the performance of the proposed AROMA framework using a real experimental test-bed setup as illustrated in Fig. 3, consisting of: two Raspberry Pis running the Open vSwitch (OVS), another two Raspberry Pis running the Hostapd along the OVS to enable IEEE 802.11a wireless access, one ONOS SDN controller is configured to manage the four Raspberry Pis, one wireless host for the video user and two more wireless hosts for generating background traffic using Iperf. A summary of the hardware used in the experimental setup is listed in Table I.

The multimedia server stores five copies of the same video content encoded at different quality levels (QL), such

as: QL1 - 3Mbps, QL2 - 2.5Mbps, QL3 - 2Mbps, QL4 - 1.5Mbps, and QL5 - 1Mbps.

B. Experimental Scenarios

Several experimental scenarios are considered to validate the performance of the AROMA framework over the multimedia-oriented SDN-based wireless experimental test-bed setup from Fig. 3. Consequently, three scenarios are defined as follows:

- Scenario 1 - *Wired Congestion* - this scenario studies the re-routing function of the AROMA framework by creating a congested link in the wired part of the network. For this purpose background traffic BG2 is used to generate traffic (Server - S2 - S3 - S4 - BG2) and create a wired congested link on S2-S3 which is shared with the video transmission of the video user that is using the shortest path (Multimedia Server - S2 - S3 - Video User). At detection of congestion AROMA routing will re-route the video transmission over Multimedia Server - S2 - S1 - S3 - Video User. The quality of the video transmission when AROMA routing is used will be compared with the shortest path case in terms of throughput, packet loss and PSNR. Here, PSNR is calculated based on the packet loss rate and the average bitrate of the multimedia stream as resulted after the encoding process using the equation introduced in [20].
- Scenario 2 - *Wireless Congestion* - this scenario studies the video adaptation function of the AROMA framework by creating a congested wireless network. For this purpose background traffic BG1 is used to generate traffic within the wireless network which is shared with the video user. At detection of packet loss AROMA adaptation will adapt the video transmission at a lower quality level, to reduce the impact of the packet loss. The quality of the video transmission when AROMA adaptation is used will be compared with the non-adaptation case in terms of throughput, packet loss and PSNR.
- Scenario 3 - *Wired and Wireless Congestion* - this scenario studies both the re-routing and adaptation functions of the AROMA framework by combining Scenario 1 and 2. Thus, in this case both background traffic BG1 and BG2 are used to create congestion in the wired as well as the wireless part of the network. AROMA will react by re-routing the video transmission over Multimedia Server - S2 - S1 - S3 - Video User as well as adapting to a lower quality level. The quality of the video transmission when AROMA is used will be compared with the shortest path and no-adaptation case in terms of throughput, packet loss and PSNR.

V. RESULTS AND DISCUSSIONS

This section presents the results of the considered scenarios and discusses the limitations of the test-bed and further possible improvements.

TABLE II
SCENARIO 1 RESULTS

Parameter	Shortest Path	AROMA routing
Average Throughput [Mbps]	2.86	2.93
Packet Loss Ratio [%]	4.85	2.3
PSNR [dB]	26.28	32.76
Perceived Quality	Poor	Fair

TABLE III
PSNR TO MOS MAPPING

PSNR [dB]	MOS Level	Perceived Quality
≥ 45	5	Excellent
$\geq 33 \& < 45$	4	Good
$\geq 27.4 \& < 33$	3	Fair
$\geq 18.7 \& < 27.4$	2	Poor
< 18.7	1	Bad

A. Results of Scenario 1 - Wired Congestion

For scenario 1, we assume that the video user is receiving the highest quality level (QL1 - 3Mbps). When AROMA detects congestion on the S2-S3 wired link, it will re-route the video transmission over the following path Multimedia Server - S2 - S1 - S3 - Video User. The results are listed in Table II. The PSNR to Mean Opinion Score (MOS) mapping is done based on Table III as proposed in [21]. It can be noticed that when using AROMA routing there is a 53% decrease in packet loss ratio as well as 25% increase in PSNR from *Poor* to *Fair* when compared to the shortest path solution.

B. Results of Scenario 2 - Wireless Congestion

In scenario 2, the wireless network where the video user is located becomes congested and AROMA adaptation will have to adapt the video transmission to a lower quality level. In this scenario we look at the impact of the packet loss when AROMA adaptation module will adapt the video transmission to any of the five quality levels (e.g., from QL1 to QL5) when compared to the case of sending only one quality level, such as QL1. The results are listed in Table IV and Fig. 4. It can be noticed that when streaming QL1, the user perceived quality is *Fair*. However, by adapting to a lower quality level, for example QL2, QL3 or QL4 the user perceived quality could increase to *Good*. Additionally, by dropping the quality level even further to QL5, the video transmission will suffer only 0.57% packet loss which translates into an *Excellent* user perceived quality.

TABLE IV
SCENARIO 2 RESULTS

Parameter	QL1	QL2	QL3	QL4	QL5
Average Throughput [Mbps]	2.89	2.44	1.96	1.47	0.99
Packet Loss Ratio [%]	2.73	1.8	1.28	1	0.57
PSNR [dB]	31.27	34.89	37.85	40	45
Perceived Quality	Fair	Good	Good	Good	Excellent



Fig. 4. Scenario 2 PSNR and MOS for each QL

TABLE V
SCENARIO 3 RESULTS: ADAPT ONLY VS. ADAPT AND RE-ROUTE

Parameter	Adapt Only				
	QL1	QL2	QL3	QL4	QL5
Average Throughput [Mbps]	2.8	2.35	1.86	1.39	0.97
Packet Loss Ratio [%]	4.95	3.98	3.35	2.8	2.3
PSNR [dB]	26.10	28.00	29.49	31.05	32.76
Perceived Quality	Poor	Fair	Fair	Fair	Fair
Parameter	Adapt and Reroute				
	QL1	QL2	QL3	QL4	QL5
Average Throughput [Mbps]	2.93	2.45	1.96	1.48	0.99
Packet Loss Ratio [%]	2.15	1.92	1.8	1.27	0.97
PSNR [dB]	33.35	34.33	34.89	37.92	40.26
Perceived Quality	Good	Good	Good	Good	Good

C. Results of Scenario 3 - Wired & Wireless Congestion

In scenario 3, the wired (S2 - S3 link) part of the network as well as the wireless network where the video user is located are congested and AROMA framework will have to adapt the video transmission to a lower quality level as well as re-route it over the path: Multimedia Server - S2 - S1 - S3 - Video User. In this scenario we look at the impact of the packet loss when both AROMA adaptation module

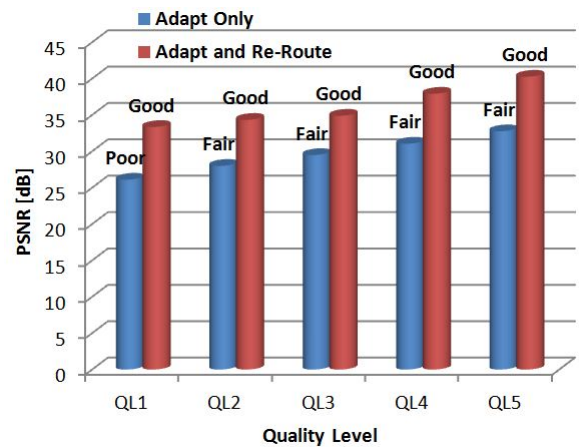


Fig. 5. Scenario 3 PSNR and MOS for Adapt Only vs. Adapt and Re-Route

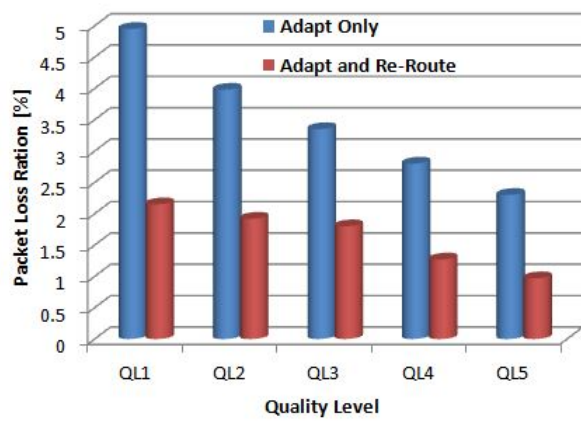


Fig. 6. Scenario 3 Packet Loss Ratio for Adapt Only vs. Adapt and Re-Route

will adapt the video transmission to any of the five quality levels (e.g., from QL1 to QL5) as well as the AROMA routing will route them on a less congested path, and compare this situation to the case of sending only one quality level, such as QL1 or using only the AROMA adaptation module without re-routing. The results are listed in Table V and Fig. 5 and Fig. 6. It can be noticed that in this case, when streaming QL1 with Adapt only and shortest path, the user perceived quality is *Poor*. However, by adapting to a lower quality level, for example QL2 to QL5 the user perceived quality could increase to *Fair*. Additionally, if AROMA adaptation and re-routing are employed together, the user perceived quality is further increased to *Good*. In this case there is a 56% drop in packet loss rate for QL1 when using AROMA with adaptation and re-routing compared to the case where the shortest path is used.

VI. CONCLUSIONS

This paper proposes AROMA, an Adapt-or-reRoute strategy for Multimedia Applications over SDN-based wireless environments. A real experimental test-bed is setup and the performance of AROMA is evaluated under three considered scenarios, such as: wired congestion, wireless congestion and wired and wireless congestion. The performance evaluation is done in terms of throughput, packet loss, PSNR and MOS. We can notice that under both wireless and wired congestion, by employing AROMA the video transmission will be adapted to a lower quality level accordingly and re-routed through a less congested path leading to an increase in the user perceived quality, from *Poor* to *Good*.

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